QUARTERLY TECHNICAL REPORT
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Principal Investigator: J. David Cohen
Organization: University of Oregon

We report the results of our research activities under NREL Subcontract ADJ-2-30630-17 during the first quarter of Phase III. During this quarter we have carried out projects primarily related to the Narrow Gap Materials reporting umbrella.

We concentrated our work during this period on the microcrystalline Si samples that we previously received from United Solar Ovonics Corp. We will continue to refer to this material in our reports as nc-Si:H. We have been examining 5 of these samples: Three of the samples are a 3-layer sandwich consisting of a 700nm thick nc-Si:H layer clad between two 200 to 250nm thick a-Si:H layers in a SS/n+/a-Si:H/nc-Si:H/a-Si:H structure upon which we deposited a semitransparent Pd Schottky barrier contact. These samples were deposited with varying levels of H-dilution. Two additional samples were purely nc-Si:H p-i-n devices containing a 1000 nm intrinsic layer in a SS/n^+/i/p^+/TCO structure. For this report we will concentrate on results for two of these samples: 14657 (sandwich) and 12123 (pin). Extensive results on an additional sandwich sample, 14140, were given in our previous reports.

Transient photocapacitance (TPC) spectra for sample 14657 are displayed in Fig. 1 for three measurement frequencies. Although these sub-band-gap spectra appear similar to sub-band-gap optical absorption spectra, the TPC signal actually results from the net transfer of charge optically excited out of the depletion region. This is an important aspect of the TPC method which results in the strong temperature dependence that appears in Fig. 1. At the lowest

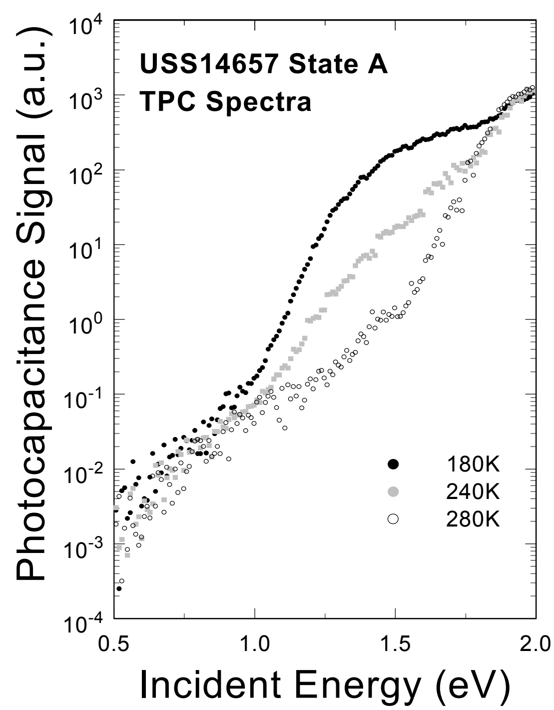

FIG. 1. Photocapacitance spectra for sandwich device 14657 at 3 measurement temperatures. Note that the microcrystalline character becomes more a-Si:H like as the temperature is increased while, at 180K, the spectrum agrees quite well with sub-band-gap spectra for nc-Si:H obtained from CPM measurements.

measurement temperatures we see that a sub-band-gap spectrum characteristic of nc-Si:H is exhibited. That is, this spectrum reveals strong absorption above the band-gap energy of 1.1eV plus some absorption below 1eV that is due to defects within the gap. Such spectra agree qualitatively quite well with sub-band-gap spectra obtained by CPM [5-8]. However, as the temperature is increased the spectrum becomes more and more similar to that of a-Si:H. As we have discussed in our earlier reports, this is due to the suppression of the nc-Si:H signal component when a majority of minority carriers is able to escape the depletion region during the photocapacitance measurement time window. This cancels the charge change (and hence the photocapacitance signal) caused by the escape of the optically excited majority carriers that is dominant at the lower temperatures. In contrast, the minority carriers generated in the amorphous silicon component of the sample appear to remain trapped and so this component of the sample dominates the spectrum above 280K. A quite similar set of spectra was reported previously for sandwich device sample 14140.

In Fig. 2(a) we display the temperature dependence of these TPC spectra near 1.25eV in more detail. In Fig. 2(b) we then plot the magnitude of the photocapacitance signal in this energy regime as a function of inverse measurement temperature. We see that temperature dependence appears thermally activated. This suggests the existence of particular defect that dominates the trapping of holes, and then allows their thermal re-emission with a characteristic energy of about 120meV.

The photocapacitance spectra for the p-i-n sample 12123displayed in Fig. 3 also exhibit strongly temperature dependent TPC spectra and an obvious amorphous silicon component at

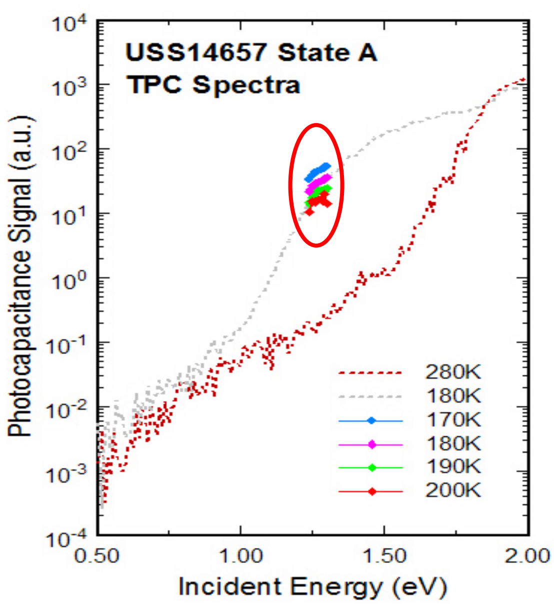

FIG. 2(a). More detailed temperature dependence of TPC spectra near a 1.25eV optical energy (region within red ellipse). The magnitude of the TPC magnitude vs. 1000/T is plotted in Fig. 2(b).

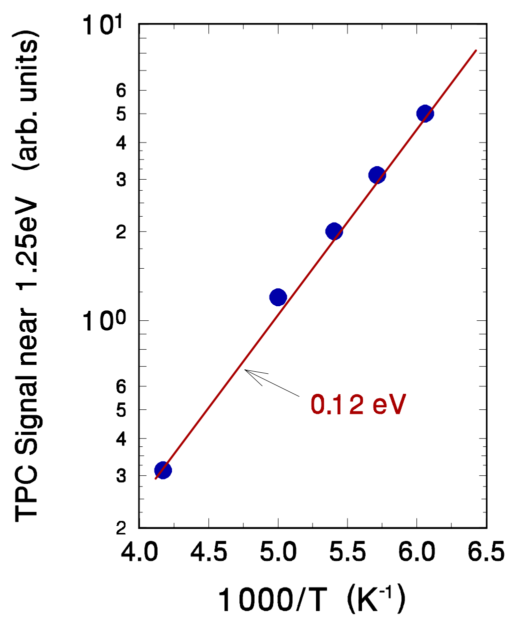

FIG. 2(b). Arrhenius plot of the temperature dependence of the photocapacitance signal near an optical energy of 1.25eV. This activation energy appears to be characteristic of the de-trapping process of trapped holes in the nc-Si:H component of these samples.

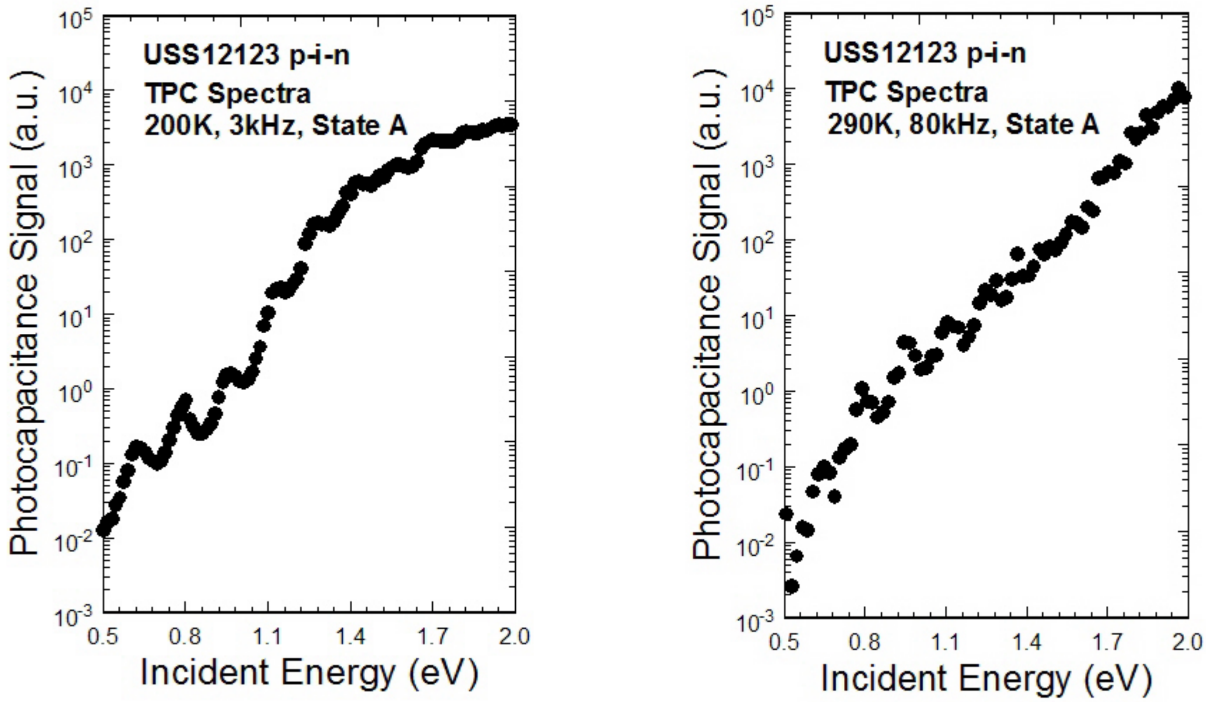

FIG. 3. Photocapacitance spectra for one pin sample at two measurement temperatures. This sample again exhibits more of an a-Si:H shaped spectrum at higher temperature, although it appears much less well formed and substantially more disordered than the spectra for sample 14657 displayed in Fig. 2.

higher temperature, although not as strong as in the sandwich sample devices. Thus we must still consider whether it is possible that the a-Si:H TPC signal component in those sandwich sample devices is enhanced by the presence of the actual layers of a-Si:H which may be contributing to the TPC response. However, a stronger a-Si:H signal in the sandwich samples is expected because the nc-Si:H layers in those samples probably actually contain a larger a-Si:H component. This occurs because the i-layer was deposited onto an amorphous Si substrate layer rather than a microcrystalline n^+layer. Such substrate differences are well known to greatly influence the transition between microcrystalline and amorphous silicon growth.[1]

Recent studies on the performance of nc-Si:H solar cell devices fabricated at United Solar [4] have revealed a 7 to 10% loss in efficiency after prolonged exposure. However, in our previous report we noted that no evidence for changes in the electronic properties were found in either our admittance or DLCP measurements. However, we did see evidence for light induced changes in the TPC spectra of sandwich sample 14140 indicating a decrease in the efficiency of minority carrier collection.

The pin sample was exposed to red filtered ELH light at an intensity of $1 W/cm^2$ for periods of 1, 3, 10, and 30 hours. After each exposure the sample was characterized using photocapacitance spectroscopy at In Fig. 4(a) we display a series 200K TPC spectra for this sample in State A and after both 10 and 30 hours of light soaking. In Fig. 4(b) we display our previously reported spectra on sandwich sample 14140 after similar degrees of light soaking also recorded at 200K. At this temperature the nc-Si:H spectral response is clearly the dominant component that is observed in both samples.

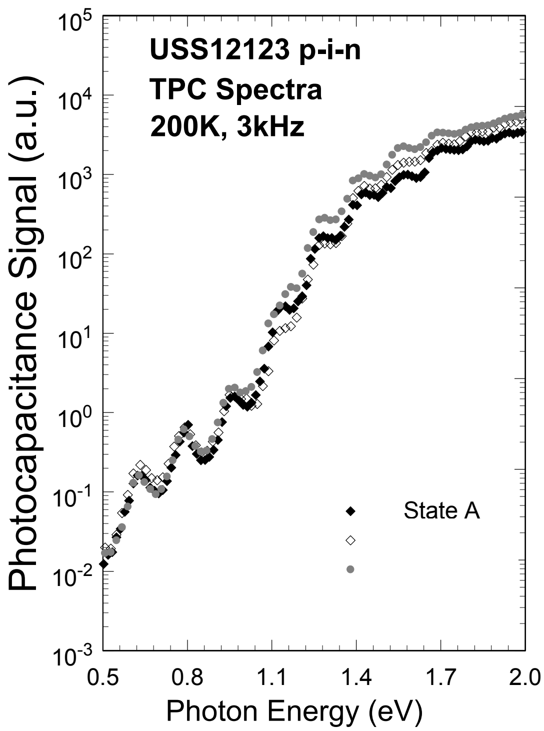

FIG. 4(a). Photocapacitance spectra for pin sample 12123 in State A and after two periods of light soaking. The *increase* in magnitude of the signal near 1.4eV indicates a *decrease* in the hole carrier collection fraction.

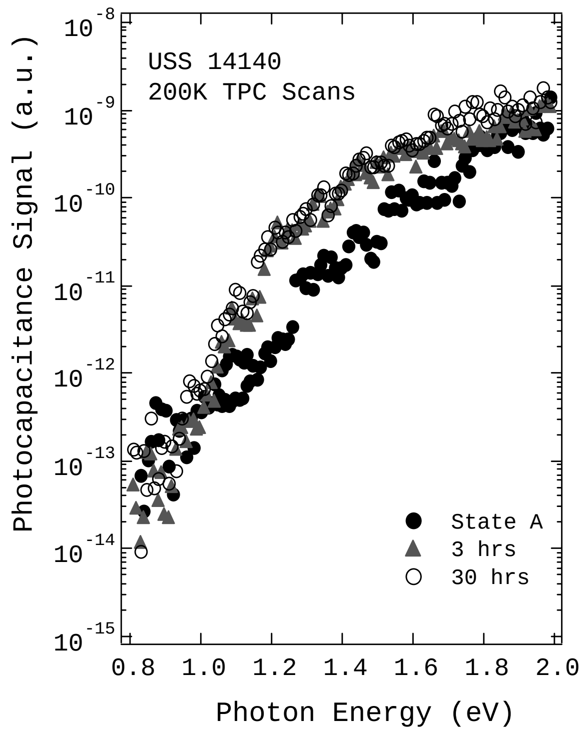

FIG. 4(b). Photocapacitance spectra previously obtained for sandwich sample 14140. Again we note changes that indicate a decrease in hole collection. However, the initial change from state A is much larger in this case.

Although little change is observed beyond 30 hours of light soaking at 200K in eiher of these samples, continuing changes are evident if we increase the temperature. At the present time we are unable to propose any particular change in the electronic structure that may be responsible. In particular, very little change in the deep defect band in Fig. 4(a) [the energy regime below 0.8eV] seems to occur as a result of light soaking. (Note that, because of poorer signal quality, the spectra in Fig. 4(b) only extend to 0.8eV so that potential changes in the deep defect band regime are not visible.) Further studies on these samples are being continued to gain additional insight into the light-induced degradation processes in these nc-Si:H samples.

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1. S. Guha, J. Yang, D.L. Williamson, Y. Lubianiker, J.D. Cohen, and A.H. Mahan, Appl. Phys. Lett. **74**, 1860 (1999).